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What is the link between synaesthesia and sound symbolism?

Kaitlyn Bankieris^{a*} and Julia Simner^{b,c}

^aUniversity of Rochester
Brain and Cognitive Sciences
358 Meliora Hall
Rochester, NY 14627

^bUniversity of Sussex
School of Psychology
Pevensey Building
Falmer, UK BN19QH

^cUniversity of Edinburgh
Department of Psychology
7 George Square
Edinburgh, UK EH89YL

*corresponding author; Email addresses: kbankieris@bcs.rochester.edu (Kaitlyn Bankieris)

Abstract

Sound symbolism is a property of certain words which have a direct link between their phonological form and their semantic meaning. In certain instances, sound symbolism can allow non-native speakers to understand the meanings of etymologically unfamiliar foreign words, although the mechanisms driving this are not well understood. We examined whether sound symbolism might be mediated by the same types of cross-modal processes that typify synaesthetic experiences. Synaesthesia is an inherited condition in which sensory or cognitive stimuli (e.g., sounds, words) cause additional, unusual cross-modal percepts (e.g., sounds trigger colours, words trigger tastes). Synaesthesia may be an exaggeration of normal cross-modal processing, and if so, there may be a link between synaesthesia and the type of cross-modality inherent in sound symbolism. To test this we predicted that synaesthetes would have superior understanding of unfamiliar (sound symbolic) foreign words. In our study, 19 grapheme-colour synaesthetes and 57 non-synaesthete controls were presented with 400 adjectives from 10 unfamiliar languages and were asked to guess the meaning of each word in a two-alternative forced-choice task. Both groups showed superior understanding compared to chance levels, but synaesthetes significantly outperformed controls. This heightened ability suggests that sound symbolism may rely on the types of cross-modal integration that drive synaesthetes' unusual experiences. It also suggests that synaesthesia endows or co-occurs with heightened multi-modal skills, and that this can arise in domains unrelated to the specific form of synaesthesia.

Keywords: sound symbolism, iconicity, synaesthesia, synesthesia, Mechanical Turk, MTurk

1 Introduction

Sound symbolism is a property of certain words which have a direct link between their phonological form and their semantic meaning. There is a rich history of research into sound symbolism, starting perhaps with Köhler (1929), who found that participants shared preferences for the naming of novel objects: they reliably matched nonwords such as *baluma* to rounded shapes, and nonwords such as *takete* to angular shapes. This finding has been extended by other authors, who suggest this shows a non-arbitrary relationship between sound and meaning: that there is something 'rounded' about the sounds comprising *baluma* and something 'angular' about *takete* (Davis, 1961; Maurer, Pathman, & Mondloch, 2006; Ramachandram & Hubbard, 2001).

Sound symbolism also occurs in the real words of natural languages. English speakers are able to guess the meanings of foreign dimensional adjectives (e.g., meaning: *big/small*, *round/pointy*, *fast/slow*, etc.) at above-chance levels, for words in Albanian, Dutch, Gujarati, Indonesian, Korean, Mandarin, Romanian, Tamil, Turkish, Yoruba, Chinese, Czech, Hindi, Japanese, and Tahitian (Brown, Black, & Horowitz, 1955; DeFife, Nygaard, & Namy, 2014; Klank, Huang, & Johnson, 1971, Kunihiro, 1971). This again suggests some inherent clues to meaning in the form of those words. Berlin (1994) demonstrated the presence of sound symbolism beyond dimensional adjectives, in a study investigating bird and fish names in the Peruvian language Huambisa; native English speakers correctly categorised bird names at rates significantly higher than chance (Berlin, 1994). An acoustic analysis of these words revealed that high frequency segments characterised bird names while low frequency segments characterised fish names. This demonstrates that the Huambisa language contains sound symbolic phonological patterns to distinguish bird and fish names, and furthermore, that native English speakers are capable of decoding these patterns. Farmer, Christiansen, and Monaghan (2006) also demonstrated the presence of sound symbolism within English, finding that English nouns and verbs have category-typical phonological properties and, furthermore, that listeners are sensitive to these properties during on-line processing tasks. The cross-linguistic presence of sound-to-meaning mappings, and the ability to deduce sound-to-meaning mappings in other languages, suggests that vocabulary is not arbitrarily assigned (or processed) and that it may be guided by shared cross-modal mechanisms. Nonetheless, the exact nature of these mechanisms is not well understood.

In the present study, we sought a better understanding of sound symbolism by comparison with a case of extreme cross-modal processing known as *synaesthesia*. For people with synaesthesia, sensory or cognitive stimuli (e.g., written words) induce the experience of unusual additional percepts, either in the same modality (e.g., the colour red) or in a different modality (e.g., the taste of oranges). *Grapheme-colour synaesthetes*, for example, experience colours triggered by reading, hearing, saying or thinking about graphemes (e.g., *a* = red; e.g., Simner, Glover & Mowat, 2006). The condition has a genetic basis (Asher et al., 2009; Tomson et al., 2011) and is typified by anatomical differences including altered white-matter coherence (e.g., Rouw & Scholte, 2007) and grey matter volume (Weiss & Fink, 2009). Synaesthesia is thought to arise from either excess cortical connections or disinhibition of existing circuits (or both; see Bargary & Mitchell, 2008, for review). In behavioural terms, synaesthesia causes a type of unusual

'cross-talk' between modalities, and in the present study we ask whether a comparable type of cross-talk might also underlie normal linguistic sound symbolism.

It has been suggested that synaesthesia represents an enhancement or explicit manifestation of latent implicit cross-modal associations found in the general population (see below). Since sound symbolism is a case of cross-modal association, the enhanced cross-modal state of synaesthetes might afford synaesthetes superior abilities in sound symbolic tasks. In our study we asked synaesthetes and controls to guess the meanings of foreign words in languages they do not speak. If synaesthetes show superior understanding of sound symbolic meanings this would be the first explicit link between synaesthetic and sound symbolic cognition, and would provide a novel way to frame this relatively poorly understood area of language processing. Such a finding would also shed light on the unusual condition of synaesthesia, per se, by showing that synaesthetes might be unusually skilled in cross-modal tasks entirely unrelated to their synaesthesia.

A possible link between synaesthetic and 'normal' processing is already motivated by prior studies. Although synaesthetic experiences are superficially idiosyncratic from one synaesthete to the next (e.g., the letter *a* might be red for one synaesthete but green for another), many types of synaesthesia often reflect patterns found intuitively in the general population (see Simner, 2013 for review). Sound-colour synaesthetes, for example, tend to 'see' higher pitch sounds as lighter colours, and nonsynaesthetes tend to favour this same mapping by intuition, in forced-choice cross-sensory association tasks (Marks, 1974; Ward, Huckstep, & Tsakanikos, 2006). Many forms of synaesthesia follow this same general principle of reflecting nonsynaesthetes' implicit associations (e.g., Cytowic and Wood, 1984; Marks, 1974, 1987; Simner et al., 2005; Simner & Ludwig, 2012; Smilek, Carriere, Dixon, & Merikle, 2007; Ward et al., 2006). These common patterns across synaesthetes and nonsynaesthetes suggest that synaesthesia might be an exaggeration or heightened awareness of cross-modal associations present in the general population. If synaesthesia is a superior manifestation of normal cross-modality, this may allow synaesthetes to perform better than nonsynaesthetes in a range of cross-modal tasks, including perhaps, those relating to sound symbolism.

Evidence for synaesthetes' superior performance in other areas of cross-modality has been demonstrated by Brang, Williams and Ramachandran (2011). They showed that grapheme-colour synaesthetes have a heightened sensitivity to cross-modal associations in a double-flash illusion task: participants reported the number of visual flashes perceived (1 or 2) in conditions where the

flashes were accompanied by either the same number of auditory beeps, or a different number. Synaesthetes were significantly less accurate in the incongruent condition (1 flash, 2 beeps) compared to nonsynaesthetes, suggesting they more strongly integrated the visual and auditory signals. In a second task, synaesthetes benefited more from bimodal stimuli than nonsynaesthetes when detecting both unimodal (auditory beep or visual flash) or bimodal stimuli. Since grapheme-colour synaesthetes do not experience synaesthesia for flashes or beeps, these findings show that their cross-modal skills extend to stimuli beyond those involved in their specific type of synaesthesia (Brang et al., 2011; but see Neufeld, Sinke, Zedler, Emrich, & Szycik, 2012, for evidence that older synaesthetes may lose this advantage). Although synaesthetes have increased multimodal integration, it is not known if this potential advantage could also be found in 'higher level' cognitive cross-modal processing, such as the language processing of sound symbolism.

To determine whether synaesthetes have heightened awareness of sound symbolism compared to nonsynaesthetes, we employed a two-alternative forced-choice task. For each trial, participants listened to a foreign word (e.g., *aravam*: Tamil) and chose its meaning from two English antonyms (e.g., *loud* or *quiet*). We predicted that synaesthetes would have higher accuracy in this task than nonsynaesthetes. To ensure that any difference in performance across groups was not due to a general superior cognitive ability or to any increased motivation on the part of our synaesthetes (see Gheri, Chopping, & Morgan, 2008), we also tested synaesthetes on a second task (the vocabulary subtest of the *Wechsler Adult Intelligence Scale – Revised*, *WAIS-R*) where we predicted no difference between groups. It is particularly important to check for motivational biases¹, given that synaesthetes are recruited as a special population. We predict that synaesthetes will out-perform nonsynaesthetes in the sound symbolism language task but not in the vocabulary task. Finally, we also utilize this study to gain other novel information about the phenomenon of sound symbolism. Given adults' sensitivity to environmental statistics, which is well documented

¹ There is no standardisation in the synaesthesia literature when testing for this effort confound, and many studies do not test for it at all (see Gheri et al., 2009). Here we selected the *WAIS-R* vocabulary subtest because it provides a well-documented test score that can be conveniently elicited, easily compared with controls or existing norms, and which has elsewhere been evaluated in comparison to a test of effort (Test of Memory Malingering (TOMM); Tombaugh, 1996). Constantinou et al. (2005) tested 69 individuals and showed their *WAIS-R* vocabulary scores correlated with TOMM effort scores at $r=.3$, $p=.01$. This suggests our choice of test might not only show that our groups are matched on *a priori* vocabulary, but might also be a valid indicator of whether one group is trying harder than the other. We point out that multiple comparisons within Constantinou et al. (unrelated to our current interests) reduced their test-alpha to less than .01 and so a replication of the link between *WAIS-R* vocab and the TOMM would further strengthen the validity of our choice here. Finally, we invite the synaesthesia community to consider implementing a standardized motivation test, whatever that might eventually be.

in the statistical learning literature (e.g., Saffran et al., 2009; Fiser & Aslin, 2001), we ask whether the sound-meaning correspondences in our stimuli are learned during the experiment. Furthermore, we hypothesize that if learning of sound-meaning correspondences does occur during the experiment, synaesthetes may be faster to pick up on these cross-modal statistics than nonsynaesthetes (Gross, Nearing, Caldwell-Harris, & Cronin-Golomb, 2011).

2 Methods

2.1 Participants Nineteen native English-speaking grapheme-colour synaesthetes (mean age = 42.74, SD = 15.95, 3 male) were recruited from the *Sussex-Edinburgh database of Synaesthete Participants* and compensated £10.00 for participation. Fifty-seven native English-speaking nonsynaesthetes were recruited as age-matched controls (three per synaesthete). Controls were tested in Rochester, NY (n=18) and Edinburgh, UK (n=39)². Nonsynaesthetes received \$10.00/£6.00 for their participation. As an eligibility requirement, all participants reported their language history and were not familiar with any of the 10 languages represented in our stimuli (see below). Ethical approval was obtained from the Department of Psychology at the University of Edinburgh and the University of Rochester Research Subjects Review Board.

Our synaesthetes were confirmed as such using both a written questionnaire (see Simner et al., 2006) and an objective test of genuineness. In the questionnaire, all reported experiencing colours for letters and/or digits. The objective test was the behavioural gold standard test of *consistency-over-time* (see below), presented either via the diagnostic site synaesthete.org (see

² As an additional control group, we also recruited 57 age-matched controls using Amazon's Mechanical Turk, an online crowdsourcing marketplace housing a large number of studies. These controls received \$1.00 US for their participation in our main task (guessing the meanings of foreign words), commensurate with average payment rates on this platform. For these controls, ethical approval was obtained from the Department of Psychology at the University of Edinburgh. Eligibility requirements stated that the participants must be native English speakers and could not have any knowledge of the 10 languages represented in our stimuli (see section 2.2 Stimuli). Due to the difficulty of ensuring that our MTurk participants were truly native English speakers without knowledge of the languages present in our stimuli, we view data from these control subjects as a replication of that from our standardly recruited controls and, furthermore, as a validation of using MTurk for conducting research in general. Since the findings in our main task did not differ between MTurk and standardly recruited controls (see footnote 4), all following mention of our controls refers to only those that were standardly recruited. Likewise, the main body of our Results section describes the results only from our standardly-recruited controls, but with Mechanical Turkers described by footnote.

Eagleman, Kagan, Nelson, Sagaram & Sarma, 2007 for methods) and/or presented as the standard test-retest method over an extended longitudinal period (see Simner et al., 2006 for methods). Both tests identify synaesthetes as being significantly more consistent when repeatedly naming synaesthetic colours for letters a-z and digits 0-9, compared to controls inventing analogous associations. Six synaesthetes were unavailable for consistency testing, but the remaining thirteen showed the required hallmark of synaesthesia. Those who took the test at synaesthete.org (n=8) had a mean standardized score of .91 (st. dev =.25), where a score less than 1 indicates synaesthetic status (see Eagleman et al., 2007 for details). Those who (also) took part in longitudinal testing (n=11) were given a surprise re-test of their synaesthetic colours after a mean of 23.9 months (st. dev =18.3), and were 92.7% (st.dev =12.5) consistent in their colours for digits, and 78.1%³ consistency (st.dev = 24.9) for letters. This performance was significantly higher than (an additional group of) non-synaesthete controls (n=40; taken from Simner et al., 2006) who scored only 35.3% in digits (st.dev =20.1; t= 9.0, df= 49, p<.001) and 36.2% in letters (st.dev = 13.8; t= 7.4, df= 49, p<.001).

2.2 Stimuli Our stimuli comprised 400 foreign words from 10 different languages (Albanian, Dutch, Gujarati, Indonesian, Korean, Mandarin, Romanian, Tamil, Turkish, and Yoruba) which each had one of the following meanings: *big, small, bright, dark, up, down, loud, or quiet*. These words were selected from a larger database containing 1220 words with a wider range of meanings (i.e., *big/small, round/pointy, dark/bright, slow/fast, still/moving, up/down, near/far, loud/quiet, and bad/good*) sampled from a range of language families (DeFife et al., 2014). To create this database, DeFife et al. (2014) had native speakers of the 10 languages record multiple synonyms for each meaning (e.g., *big, huge, large* etc.) resulting in a database with some variation in the number of words per meaning and per language. Informants recorded words in their native language using list prosody with a neutral tone of voice. Recordings were made using Audacity software at 44.100 kHz sampling rate. Words were edited into separate files, downsampled to 22.050 kHz, and amplitude normalised.

³ Consistency was lower for letters (78%) than digits (93%), because two subjects had less pronounced colours for letters than digits. They consequently scored 30-33% consistent in the former, but 100% in the latter. Hence they still produced scores diagnostic of synaesthesia in at least one category. We included their letter scores for full disclosure.

Our words fell into one of four semantic domains (*big/small*; *bright/dark*; *up/down*; *loud/quiet*). These domains were selected in order to ask whether synaesthetes are sensitive to sound symbolism in the domain of their synaesthesia only (vision in this instance, since we recruited synaesthetes who experience synaesthetic colour) or also across other domains. Therefore, we selected dimensional adjective pairs both *within* the visual modality (*big/small*, *down/up*, and *bright/dark*) and *outside* the visual modality (*loud/quiet*). We tested only one non-visual domain to reduce the time and effort required of our participants. Our 400 stimuli words were divided into four lists of equal length according to semantic meaning (one list of $n=100$ words meaning *big/small*, another $n=100$ list for *bright/dark* and so on). Within each list, we note that the utterance-length of each word was equal across the two meanings. Hence there was no significant difference between the length of words meaning *big* versus *small* ($t=.40$, $df=98$, $p=.70$), nor *bright/dark* ($t=-.06$, $df=98$, $p=.96$), nor *down/up* ($t=.40$, $df=98$, $p=.6$), nor *loud/quiet* ($t=.96$, $df=98$, $p=.3$).

The 10 different languages were all represented within each list in a way that reflected the larger database from which our materials were drawn (mean number of words from each language within each of our lists = 10.0; range = 3-18; SD range = 3.2-4.2). DeFife et al. (2014) found that when native English speakers guessed the meanings of these words (e.g., *nana*) from two alternatives (e.g., *big* or *small*; *nana* = small) agreement was significantly higher than chance for some semantic categories, including the four categories selected as materials here. DeFife et al.'s findings suggest the presence of sound symbolism in our materials, which makes them an appropriate source of stimuli for the aims of our study.

2.3 Procedure For all participants, the study was conducted through the online survey program LimeSurvey© version 1.91+. Participants were directed to this interface via email. Prior to starting the task, participants again confirmed that they were native English speakers and did not speak any of the languages used in the task. Additionally, controls were given a description of synaesthesia to ensure that only nonsynaesthetes participated in our task. Participants provided ethical consent before proceeding to the task instructions. Instructions explained that participants would listen to foreign words and must guess their meanings from two alternatives. Stimuli were presented in four blocks, one for each semantic domain. At the beginning of each block, instructions notified participants which dimensional adjective pair would be relevant (e.g., *big/small*). Each trial displayed an audio player icon and the two answer choices. Participants

clicked the play button to hear the word and then selected the word's meaning from the two labeled choices. Each block (*big/small*, *loud/quiet*, *down/up*, *bright/dark*) occurred in each presentation position once (i.e., first, second, third, fourth) across four counterbalanced conditions. Within blocks, stimuli were presented randomly to participants. Presentation order of answer choices (e.g., *big* followed by *small* versus *small* followed by *big*) was counterbalanced.

Finally, all, participants (both synaesthetes and age-matched controls) were given the WAIS-R vocabulary subtest in a telephone interview. (Four synaesthetes were unavailable for retesting; the remaining 16 synaesthetes had a mean age = 43.33, $SD = 15.25$). The experimenter followed the standardized instructions asking participants, "What does _____ mean?" for 35 test items (e.g., *repair*, *fortitude*, *encumber*). As per test instructions, the experimenter began questioning with *Item 4*, giving full credit for *Items 1-3* if the participant passed *Items 4-8*. This was the case for all participants. If the experimenter could not determine a participant's knowledge of a word from his/her response, the experimenter prompted, "Tell me more about it" or "Explain what you mean" to obtain further information.

3 Results

Before performing our analysis, we noted that our foreign words contained 45 cognates of English. Cognates were defined as words whose meaning could be guessed based on knowledge of English alone (e.g., *larg* = "big"; Romanian). Superior performance in our task based on etymological similarity is not necessarily contradictory to the idea of sound symbolism since these etymological similarities may have been preserved throughout language evolution due to the benefit that sound symbolism yields for learning language (e.g., Imai, Kita, Nagumo, & Okada, 2008; Nygaard, Cook, & Namy, 2009). Nonetheless, we chose to exclude cognates from our analysis below to make for a stronger test of sound symbolism. Hence we performed our analyses on the remaining 355 words per subject.

3.1 Sound Symbolism task Each trial was coded as correct (1) or incorrect (0) for each subject. A correct answer was one where the participant's response (e.g., *small*) matched the meaning of the foreign word (e.g., *nana* meaning 'small'). Figure 1 displays the mean accuracies of participants according to group and semantic domain, converted to percentages. We analyzed our accuracy results using mixed effect logistic regressions fitting random intercepts by

participant, item, and language to ask four questions: (1) Are nonsynaesthetes, and are synaesthetes, significantly better than chance at determining the meanings of the words presented? (2) Do synaesthetes perform better than controls? (3) Are synaesthetes superior only within the domain of their synaesthesia (visual domain: *big/small*, *down/up*, *dark/light*) or also outside that domain (auditory domain: *loud/quiet*)? (4) Does performance improve throughout the course of the experiment? We present our analyses below in that order.

To determine if synaesthetes and nonsynaesthetes detected sound symbolism better than chance would predict, we ran a mixed effects logistic regression modeling the interaction between group (synaesthetes, controls) and domain (*big/small*, *bright/dark*, *down/up*, *loud/quiet*) as well as random intercepts by participant, item, and language. Coding in this manner fits an effect for each combination of group and domain against chance. As displayed in Figure 1, this analysis indicated that both types of participant (synaesthetes, controls) performed better than chance in the *big/small* domain ($\beta_s = 0.53$, $z = 5.29$, $p < .001$, $\beta_c = 0.41$, $z = 4.72$, $p < .001$). Synaesthetes also performed significantly better than chance in the *loud/quiet* domain ($\beta_s = 0.27$, $z = 2.96$, $p < .01$) and controls did so marginally-significantly; $\beta_s = 0.13$, $z = 1.68$, $p = .09$. Accuracy was not better than chance for any other combination of group and domain; all $\beta_s < .13$, $z_s < 1.4$, $p_s > .05$. These findings show a sensitivity to sound symbolism in a subset of our stimuli, partially replicating DeFife et al. (See discussion for a further comparison of our results).

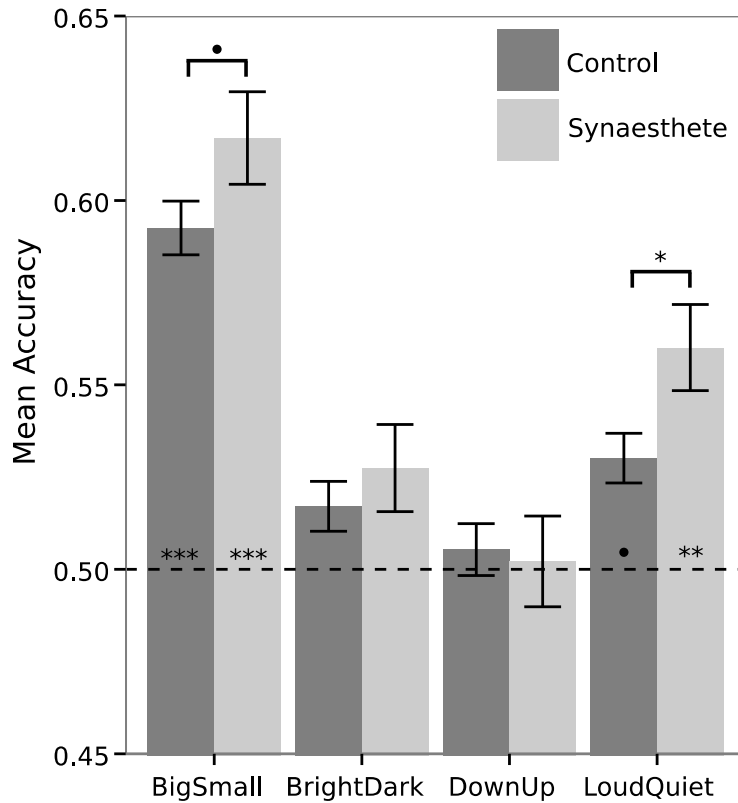


Figure 1. Mean accuracy by participant group and semantic domain. Horizontal line represents chance performance and error bars represent standard error. Asterisks above the horizontal chance line indicate significant differences between participant scores and chance. Asterisks above bars indicate significant differences between controls and synaesthetes. • $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Our main analysis of interest asked whether sound symbolism was detected better by synaesthetes than controls. We compared accuracy between synaesthetes and controls overall, and also within each of the four domains (*big/small*, *bright/dark*, *down/up*, *loud/quiet*). For these analyses, we ran a mixed effects logistic regression predicting accuracy by group, domain and their interactions. Again we fit random intercepts by participant, item and language. Our results (with domain simple coded) indicated a significant main effect of group, with synaesthetes performing better than nonsynaesthetes; $\beta = .05$, $z = 2.19$, $p < .05$. To investigate whether the effects were limited to any particular domains, we ran the above analysis with each individual domain coded as the reference level. Coding in this manner allows us to test the effect of group within each domain. Our analyses revealed that synaesthetes were significantly better than controls in the *loud/quiet* domain ($\beta = .07$, $z = 2.52$, $p < .05$), and were also marginally significantly better than

controls in the *big/small* domain; $\beta = .06$, $z = 1.72$, $p = .08$. There were no other group differences in either of the two remaining domains; *bright/dark*: $\beta = .02$, $z = .77$, $p > .05$; *down/up*: $\beta = .01$, $z = .23$, $p > .05$). Upon finding that synaesthetes' performance differed from controls the most in domains in which controls' accuracy was the highest, we ran a mixed effects logistic regression predicting synaesthetes' accuracy from controls' mean accuracy by word. We also included domain as a fixed effect and random effects of word, language, and participant. Results indicated that nonsynaesthetes' accuracy significantly predicted synaesthetes' performance; $\beta = 4.57$, $z = 23.83$, $p < .001$.

Finally, we investigated the possibility that participants might be learning sound-meaning correspondences throughout the experiment, hypothesizing that if this were true, synaesthetes may be quicker than controls to pick up on these statistical cross-modal regularities in the stimuli. To address this question, we ran a mixed effects logistic regression including main effects of group (synaesthetes, controls), domain (*big/small*, *bright/dark*, *down/up*, *loud/quiet*), and trial within block (1-100) as well as their interactions. Again, we fit intercepts by participant, item, and language. Results showed neither a main effect of trial within block on accuracy nor any significant interactions involving trial within block (all β s $< .09$, z s < 1.8 , $ps > .05$)⁴. This finding suggests that participants are not learning sound-meaning correspondences during the experiment, but rather, that they may be entering the experiment with some pre-existing correspondences.

⁴ Running these same analyses with our MTurk controls yielded a similar pattern of results. MTurk controls performed better than chance in the *big/small* domain ($\beta = 0.33$, $z = 4.93$, $p < .001$) and the *loud/quiet* domain ($\beta = 0.13$, $z = 2.17$, $p < .05$). Accuracy was not better than chance for either the *up/down* or *bright/dark* domains; all β s $< .06$, z s $< .9$, $ps > .05$. Again, we found a main effect of group synaesthetes performing better than nonsynaesthetes; $\beta = .04$, $z = 2.11$, $p < .05$. Comparing group accuracy for individual domains revealed that synaesthetes were significantly better than MTurk controls in the *big/small* domain ($\beta = .08$, $z = 2.47$, $p < .05$), and were also marginally significantly better than controls in the *loud/quiet* domain; $\beta = .03$, $z = 1.86$, $p = .06$. There were no other group differences in either of the two remaining domains; *bright/dark*: $\beta = .03$, $z = .85$, $p > .05$; *down/up*: $\beta = .03$, $z = .26$, $p > .05$). MTurk controls' average accuracy by word significantly predicted synesthetes' accuracy; $\beta = 5.63$, $z = 18.46$, $p < .001$. Finally, in our analysis investigating the possibility that participants were learning sound symbolic correspondences throughout the experiment we found neither a main effect of trial within block on accuracy nor any significant interactions involving trial within block (all β s $< .01$, z s < 1.0 , $ps > .05$). These results replicate our main findings based on real-world controls, and thereby validate the use of Mechanical Turk as a recruitment method for experimental investigations.

3.2 WAIS-R Vocabulary. Each item on the WAIS-R vocabulary test is scored 0, 1, or 2, representing knowledge of word-meaning that is, respectively: absent, correct but incomplete, or correct and complete. Following the WAIS-R manual, we converted raw scores to scaled scores based on age (Weschler, 1981). Figure 2 displays scaled scores for our synaesthetes and controls. A Shapiro-Wilk normality test indicated that our data was not normally distributed ($W = 0.97, p > 0.05$) so we conducted a Wilcoxon two-sample test to show that, as predicted, there was no difference between synaesthetes' and controls' performance on this control task ($\text{Median}_s = 13$, $\text{Median}_c = 14$, $W = 444.5, p > 0.05$).

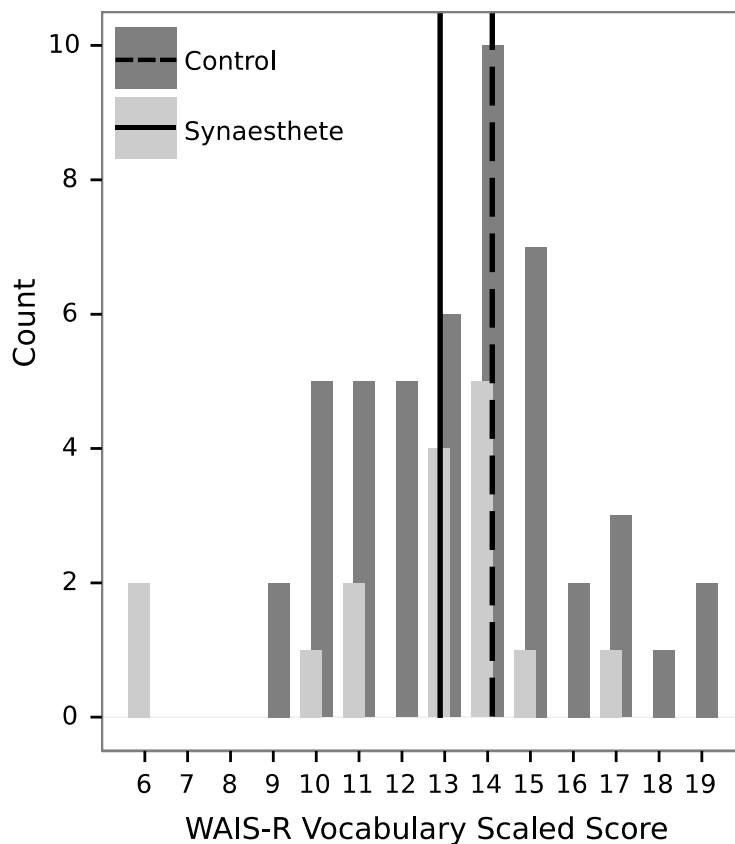


Figure 2. Synaesthetes' and controls' WAIS-R vocabulary scaled scores. Vertical lines represent medians.

4 Discussion

Our investigation has looked at sound symbolism - a linguistic property in which phonological forms map to semantic meanings, and which can sometimes allow non-native speakers to understand unfamiliar foreign words. Our aim was to shed light on a relatively poorly understood area of language by showing that sound symbolism may arise from latent cross-modal mechanisms of a type found more extremely in synaesthetes. Our data show that synaesthetes had superior sensitivities to linguistic cross-modal sound-meaning correspondences in language. Synaesthetes were able to deduce the meanings of certain foreign words not only better than chance would predict (in the semantic domain of *loud/quiet*, and *big/small*), but also significantly better than nonsynaesthetes (for words meaning *loud* or *quiet*, and near-significantly better for *big/small*). From this we can draw one of two conclusions: either synaesthetes are better at sound symbolism per se, or they have some other unknown ability mediating this performance. However, since synaesthetes performed no differently than controls on the WAIS-R vocabulary subtest, we conclude that their heightened sensitivity to sound symbolism cannot be attributed to increased motivation or superior vocabulary or general cognitive abilities in IQ (since WAIS-R vocabulary scores are highly correlated with IQ; e.g., Blaha & Wallbrown, 1982). We continue therefore with the assumption that – in the absence of other evidence – synaesthetes are superior at the cross-modal detection of sound symbolism.

Our findings have implications for both sound symbolism and synaesthesia, and we discuss these in turn here. With respect to sound symbolism, our findings support previous claims that there are consistent sound-to-meaning pairings across natural languages which can be detected even by those who do not speak that language (DeFife et al., 2014, Revill, Namy, DeFife, & Nygaard, 2014). We demonstrated that both participant groups were capable of accurately detecting meaning for certain foreign words at above-chance level (in the semantic domains of *loud/quiet* and *big/small*). Of course, finding evidence of sound symbolism in some words/languages does not mean that *all* words/languages are sound symbolic as a universal fact. Some languages may have no sound symbolism at all, or even if they do, native English speakers might not be able to detect it. By extension, even though participants were unable to detect sound symbolism in some domains here, it may yet exist as a linguistic fact (i.e., it might be detected if the appropriate linguistic analysis were performed).

Neither synesthetes nor controls performed above chance in the domains of *bright/dark* or *down/up*, which raises two questions: why did we fail to replicate DeFife et al. (2014) in this one

regard, and why might these domains be less open to non-native intuition than *loud/quiet*, and *big/small*? Our apparent failure to replicate may in fact be due to a difference in analysis: Defife et al. coded participant responses by “majority agreement” (where ‘accurate’ meant agreeing with the majority of participants, even if this was the wrong meaning of the word). This approach could cause differences in results because non-native speakers might share intuitions about phonological-semantic mappings, even if they ultimately choose an incorrect word-meaning. Interestingly, previous studies have pointed out that some languages have correspondences between the same semantic dimensions and linguistic properties but with reversed directionality (e.g., Nygaard, Cook, & Namy, 2009; Saji et al., 2013). This means that being able to intuit valid sound symbolic relationships might produce an inaccurate answer if applied to a different language. Given all this, we re-ran our analysis using the “majority agreement” coding method of Defife and colleagues, and subsequently replicated their effect: A mixed effects logistic regression modeling the interaction between group (synaesthetes, controls) and domain (*big/small*, *bright/dark*, *down/up*, *loud/quiet*) with random intercepts by participant, item, and language showed that both groups in all domains had a mean agreement above chance (all β s > .31, z s > 4.5, p s < .001). This suggests that our participants may have reversed the direction of foreign correspondences for words meaning *bright/dark* or *down/up*, and it also suggests that overall, our data was likely to have been largely comparable to Defife et al. (2014).

Replicating Defife et al. (2014) in this manner answers one scientific question, but does not address why *bright/dark* and *down/up* patterned differently than *big/small* and *loud/quiet* in our original analysis, where we considered true accuracy. Put differently, why are non-native speakers better than chance at guessing the meanings of *big/small* and *loud/quiet*, but not *bright/dark* and *up/down*? One possible explanation stems from the hypothesis that sound symbolism originated from mimicking properties of intended referents (e.g., size) with physical aspects of the human vocal tract (e.g., size of oral cavity) and/or its auditory production (e.g., higher frequency sounds produced for small items (e.g., Sapir, 1929). Perhaps the domains for size and loudness are easier to mimic iconically in the auditory domain than brightness and direction yielding consistent sound-meaning correspondences cross-linguistically (see Imai & Kita, 2014 for a discussion of universal vs. language-specific sound symbolism). Another possible explanation for why *bright/dark* and *up/down* were not guessed better than chance, is that brightness (*bright/dark*) and direction (*up/down*) may perhaps be coded with prosody rather than

information inherent to segmental features. We make this suggestion for specific two reasons. The foreign language speakers who recorded the stimuli for the present study were instructed to produce the words with a neutral tone of voice in an effort to minimize the influence of prosody on participants' judgements (Defife et al., 2014). Indeed, our post-hoc analyses show no difference in mean spectral centroids between words meaning *bright* and *dark* (Median_B = 76.94, Median_D = 79.77, Wilcoxon $p > .05$) or *down* and *up* (Median_D = 75.59, Median_U = 77.45, Wilcoxon $p > .05$). Therefore our participants would not have been able to guess the meanings of foreign words in the *bright/dark* and *down/up* domains if such delineations are naturally encoded with prosodic information, because this was not present in our stimuli (Shintel, Nusbaum, and Okrent, 2006). A second reason to consider prosody is that cross-modal correspondences between pitch and brightness as well as pitch and direction (up/down) have indeed been found (Marks, 1974; 1987) suggesting that prosody may indeed be used for determining meaning in these domains. Further research addressing the role of prosody in different semantic domains is therefore needed.

Our synaesthetes' superior ability in detecting foreign word-meanings suggests that sound symbolism mechanisms might helpfully be understood in terms of the types of cross-modality found heightened in synaesthetes. Consider first that synaesthetes show explicit enhanced 'cross-talk' between otherwise unrelated modalities (e.g., between sound and vision in audio-visual synaesthesia) and that this has been tied to structural and functional differences in the brains of synaesthetes (e.g., Hänggi, Wotrubua, & Jäncke, 2011; Dovern et al., 2012; Rouw & Scholte, 2007; Weiss & Fink 2009; Hubbard, Arman, Ramachandran, & Boynton, 2005). Importantly, synaesthetic experiences are often reflective of non-synaesthetes' intuitions (see Simner, 2013 for review). For example, audio-visual synaesthetes tend to see lighter colours for higher pitch sounds, and indeed, light colours and high pitch are linked intuitively by all people (Ward et al., 2006). Hence, although synaesthetes have different brains and unusual perceptions, these differences may represent a more extreme manifestation of the normal cross-modal status of all people. Below we briefly explore this further, and show how this, in combination with our current findings, might help us to understand the basis of sound symbolism more clearly.

In developmental terms, the shared intuitions of synaesthetes and non-synaesthetes have been explained by the *neonatal synaesthesia hypothesis* (Maurer 1993; Maurer & Maurer 1988; Maurer & Mondloch 2004) which suggests that adult synaesthesia may be a reflection of early synaesthetic states found in all neonates. This theory points out that the brains of both adult

synaesthetes and all neonates show abundant cortical connectivity and thicker grey matter (e.g., Gogtay et al., 2004) in turn suggesting that all people may have synaesthesia-like experiences in early life. In most cases, this early hyper-connectivity is attenuated by normal developmental neural pruning (leaving in adulthood only remnants of the earlier childhood state) but this process may fail in synaesthetes (see Maurer, Gibson, & Spector, 2013, for a recent review). Our findings here allow us to posit an additional function for this “remnant of synaesthesia” in typical adults, specifically in the domain of human language. We suggest that the types of connectivity that remain active in synaesthetes may allow superior performance in sound symbolism tasks *precisely because* their implicit correlates in non-synaesthetes form the basis of how sound symbolism is understood by the average person.

Our findings can also be interpreted in relation to Imai and Kita's (2014) sound symbolism bootstrapping hypothesis. In particular, this study can be used to evaluate the claim that neural pruning throughout development narrows one's range of sound symbolism sensitivity (i.e., children are sensitive to universal sound symbolism whereas adults are sensitive only to language specific sound symbolism). Combining this claim with the idea that synesthesia arises from an abundance of neural connections or a lack of pruning, one would predict that synesthetes, like children, are sensitive to a wider *range* of sound symbolic correspondences than non-synesthetic adults. We found that nonsynesthetes' accuracy predicted synesthetes' accuracy on our sound symbolism task, suggesting that synesthetes are not sensitive to a wider range of sound symbolism, *per se*, but have heightened sensitivity to the same sound symbolic correspondences that nonsynesthetes are sensitive to. However, since our study was not designed to compare sensitivity to universal and language specific sound symbolism, further research is needed to properly address this prediction.

To understand this in neurological terms it is important to know that the brains of synaesthetes show altered connectivity and function in areas not just limited to the synaesthetic percept. For example, synaesthetes experiencing colours show brain differences not only in colour-coding regions (e.g., V4) but also in more widespread areas, including frontal and parietal regions (see Rouw, Scholte & Colizoli, 2011 for review). This suggests synaesthetes may have cross-modal differences beyond the synaesthetic percept itself, and this is where the link between synaesthesia and cross-modal sound symbolism may lie. Recent neuroimaging of sound symbolism indicates a role for left superior parietal cortex (Revill et al., 2014) and we point out

here that this same region has previously been implicated in synaesthesia, as well as in individual differences in cross-modal processing (Brang et al., 2013; Rouw & Scholte, 2007). Parietal involvement is often tied to the idea of synaesthesia as an extreme form of 'binding' (e.g., Rouw et al., 2011) and so neurological similarities across synaesthesia and sound symbolism perhaps suggest we could look to parietal binding mechanisms as the shared apparatus underlying both phenomena.

Our findings here also support previous proposals for a link between synaesthesia and sound symbolism in language evolution. Ramachandran and Hubbard (2001) hypothesised that synaesthesia-like remnants present in the general population may have played a guiding role in the evolution of a proto-language based on sound symbolism. This idea has been extended further in a recent review by Cuskley and Kirby (2013). Our own study has shown that the cross-modal mechanisms that are explicit in synaesthetes may indeed aid them when understanding sound symbolic words, and we suggest this may have facilitated comprehension in early states of vocabulary development in language evolution. If synaesthetes are especially good at understanding never-before-heard words, then they may have been an especially adept group at bridging problems of mutual intelligibility in the evolution of protolanguage. In this way, synaesthetes (with their greater grasp of cross-modality) might have been effective conduits for generating or propagating proto-words that might be mutually intelligible within early speech communities. In addition, the fact that synaesthetes are exceptionally sensitive to the same sound-meaning correspondences as nonsynaesthetes suggests that exploiting the comparable implicit associations in nonsynaesthetes could be an effective way to bridge the problem of mutual intelligibility in the evolution of language. Hence, we provide support for the cross-cultural and cross-modal neural hypothesis of language evolution originally hypothesised by Ramachandran and Hubbard (2001; also Cuskley & Kirby, 2013).

In relation to synaesthesia per se, we have provided evidence that synaesthetes' unusual cross-modal endowments extend beyond the synaesthetic percept itself. Previous studies have already suggested synaesthetes show enhanced cross-modality beyond synaesthesia in perceptual tasks (e.g., in audiovisual integration in the double-flash illusion; Brang et al., 2011) and our own study now extends this to a cognitive task. Our synaesthetes were able to deduce underlying links between semantics and phonology to a significantly greater degree than nonsynaesthetes, suggesting synaesthesia may involve a relatively *widespread* exaggeration of normal cross-modal

processing. Furthermore, our synaesthetes with unusual visual experiences (i.e., colours) demonstrated sound symbolic sensitivities not only in semantic domains of vision (i.e., for words meaning *big/small*) but also in the semantic domain of audition (i.e., for words meaning *loud/quiet*). Had our findings been restricted to vision-related words only, one might have argued that synaesthetes' enhanced visual perception was somehow feeding back into their language representations (e.g., via language embodiment; e.g., Simmons et al., 2007). Instead, we found more generalized sound symbolic abilities extending beyond the particular form of synaesthesia, both cognitively (i.e., beyond perception, to phonological-semantic integration) and linguistically (i.e., beyond the semantics of vision, to a semantic domain relating to audition).

Our methodology enables us to show that participants perform better than chance in two-alternative forced-choice demonstrations of sound symbolism, but does not let us gauge how powerful that effect might be in more every-day situations of language exposure. Furthermore, the current experiment can only speak to mechanisms underlying the specific sound-meaning correspondences tested here. It is possible that other general forms of sound symbolism (e.g., sound to grammatical class; Farmer et al., 2006) are driven by different mechanisms. Moreover, our task inherently limits our detection of sound symbolism to precise mappings from sound-to-meaning (i.e., *nana* – small) rather than allowing for more general mappings (i.e., *nana* – size). Previous research demonstrates that antonyms are quite conceptually similar, differing only on one dimension (Murphy & Andrew, 1993) and that pairing a foreign word with its English antonym leads to increased learning compared to a random pairing (Nygaard, Cook, & Namy, 2009). Thus it is possible that domains failing to reach significance in this study are sound symbolic on a broader level than our task is capable of detecting. Nonetheless, our findings suggest that certain non-arbitrary mappings from sound to meaning are detectable without any specific language experience. We addressed the possibility that participants were learning the sound-meaning correspondences within the course of our experiment and found no evidence of such learning. Thus, our results suggest that our participants entered the experiment with pre-existing sound-meaning correspondences. The exact nature of the phonological cues that synaesthetes might be sensitive too is outside the scope of this paper (see Namy, Mathur, DeFife, & Nygaard, 2014 for phonological cues that nonsynaesthetes are sensitive to), but we can conclude at least that it is not from utterance length, since this was controlled in our study.

To our knowledge, this is the first study investigating common sound symbolic correspondences between synaesthetes and nonsynaesthetes. While synaesthetes were more sensitive to sound-meaning correspondences, it is important to note that they were sensitive to the same types of sound symbolic associations as nonsynaesthetes. Specifically, synaesthetes performed better than controls only in domains that controls performed better (or nearly better) than chance. Thus, our study supports synaesthesia as a more general exaggeration of common cross-modal connections, rather than a qualitatively different phenomenon. Our study examined the performance of grapheme-colour synaesthetes, and future studies might also ask whether this extend to other types of synaesthetes, such as music-color synaesthetes. A renewed interest in synaesthesia in the last decade has given a relatively deep understanding of this unusual condition. A comparably less developed focus of study, however, has been to use synaesthesia to inform about theories of normal cognition – as we have done here -- despite several calls for this more traditional neuropsychological approach (Cohen Kadosh & Henik, 2007; Simner, 2007). We conclude that synaesthetes' extraordinary ability in detecting sound-meaning correspondences provides a window onto the mechanisms of sound symbolism itself, a relatively poorly understood phenomenon. Our data also suggest that synaesthesia is a condition involving a general exaggeration of cross-modal abilities, rather than abilities limited to the (albeit extraordinary) experiencing of synaesthetic percepts alone.

5 References

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